Title: Assume-guarantee contracts for control of cyber-physical power systems

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DESCRIPTION OF THE THESIS:

- Keywords

Assume-guarantee contracts, microgrids, cyber-physical systems, correct-by-design verification

- Context

In power systems in general, and in microgrids in particular, existing approaches are not capable of fully exploiting the potential of Cyber-Physical Systems (CPSs) [1], i.e. physical systems augmented with computation and communication infrastructure making it possible to design highly dynamic systems able to perform efficiently under high uncertainty. Considering microgrids as CPSs is one of the means to facilitate the integration of new components (new storage devices, connections with a new microgrid, Plug&Play of renewables, etc). The physical layer comprising of power/energy infrastructures and the cyber layer comprising control, communication, and computation need to be designed to achieve the overall goals of energy sustenance. Thanks to their reconfigurable structure, CPSs can support the definition of the modern power systems as a flexible and resilient composition of microgrids, thus facilitating the possibility to decompose them in more manageable sub-systems and to favor the integration of new components.

Contract theory [2,3] is a promising framework for rigorous component-based design of highly dynamic distributed systems, thus permitting the correct-by-design definition of cyber-physical power systems (CPPSs). Intuitively, a contract is a formal specification consisting of pairs of assumptions and guarantees. A guarantee describes the task that the component must fulfill when its environment (made of other components and of the external environment) satisfies the associated assumption. Hence, assume-guarantee contracts make it possible to design components that can adapt under various working conditions. Moreover, compositional reasoning makes it possible to prove properties of the global system based on the contracts satisfied by its components.

Classical control approaches for power systems are hierarchical, and consider a de facto separation among the control levels according to the time scale of the considered dynamics [4,5]. Nowadays, the underlying hypothesis are outdated due to the integration of high shares of renewables and energy storage systems, and therefore there is a need for a holistic approach for the control hierarchy. Contract-based design is the promising solution for unraveling the full potential of CPPSs by merging the possibility to have correct-by-design verification of stability and synthesis of multi-level controllers.

- Scientific work

In this doctoral work, we will develop a refinement method to empower priority of actions among the control levels of microgrids and permit an efficient vertical arrangement of the control hierarchy while enhancing horizontal coordination among the several physical devices composing the microgrid. We target the following microgrid-oriented results:

- Correct-by-design verification of power systems' specifications: by considering a microgrid as a CPS in a systematic way since the design phase of the control systems, we will implement a system of systems approach based on contract theory to define the desired specifications with respect to the given components. Then, we will investigate the effects of possible interactions among the components and the optimal configurations with respect to desired requirements.
- Multi-level controller synthesis: given a contract and a component model, synthesize a controller that fulfills the contract. Based on the modeling via contracts and the possible

horizontal and vertical interactions, we target considering the hierarchy as a whole for stability purposes and to achieve a global control objective.

In the last year of the thesis, it is expected that the PhD candidate will assist a senior postdoc that will be in charge of implementing the obtained results on experimental tests.

- Required skills:

This thesis topic mainly requires good skills in control theory and mathematics. Very good results in the engineering curriculum as well as expertise in the topics related to nonlinear control will constitute strengths to the proposed subject. Knowledge of power systems and electrical grid is not necessary but is a plus.
The proposed subject should lead to the acquisition of strong theoretical skills in the field of control of power systems. In particular, the candidate will become familiar with the modeling of dynamical systems, with control design and with microgrid-oriented control problems. The candidate should also become familiar with Matlab (numerical methods, simulations) or Python.

- Application: Send

- CV
- A letter of motivation
- Master's and/or engineering studies evaluations
- A letter of recommendation from the master manager
- The coordinates of two referees

- Contact: Send your application by email to

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References:

[1] P. Derler, E. A. Lee, and A. Sangiovanni Vincentelli, "Modeling cyber–physical systems," Proceedings of the IEEE, vol. 100, no. 1, pp. 13–28, 2012.
[2] A. Benveniste, B. Caillaud, D. Nickovic, R. Passerone, J.-B. Raclet, P. Reinkemeier, A. Sangiovanni-Vincentelli, W. Damm, T. Henzinger, and K. Larsen, "Contracts for system design," Foundations and Trends in Electronic Design Automation, vol. 12, no. 2-3, pp. 124–400, 2018.
[3] A. Sangiovanni-Vincentelli, W. Damm, and R. Passerone, "Taming dr. frankenstein: Contract-based design for cyber-physical systems," European Journal of Control, vol. 18, no. 3, pp. 217–238, 2012.
[4] M. Farrokhabadi et al., "Microgrid Stability Definitions, Analysis, and Examples," in IEEE Transactions on Power Systems, vol. 35, no. 1, pp. 13-29, Jan. 2020.
[5] A. Iovine, T. Rigaut, G. Damm, E. De Santis, M. D. Di Benedetto, "Power Management for a DC MicroGrid integrating Renewables and Storages", Control Engineering Practice, Volume 85, 2019, Pages 59-79, ISSN 0967-0661.
[6] A. Saoud, A. Girard, and L. Fribourg, "Assume-guarantee contracts for continuous-time systems," Automatica, vol. 134, p. 109910, 2021.
[7] A. Girard and A. Iovine, "Invariant Sets for Assume-Guarantee Contracts", to appear in IEEE CDC, 2022.
[8] M. Mirabilio, A. Iovine, E. De Santis, M. D. Di Benedetto and G. Pola, "Scalable Mesh Stability of Nonlinear Interconnected Systems," in IEEE Control Systems Letters, vol. 6, pp. 968-973, 2022.
[9] D. Zonetti, A. Saoud, A. Girard, and L. Fribourg, "A symbolic approach to voltage stability and power sharing in time-varying DC microgrids". European Control Conference (ECC). IEEE, 2019. p. 903-909.
[10] Y. Chen, et al. "Safety-critical control synthesis for network systems with control barrier functions and assume-guarantee contracts", IEEE Transactions on Control of Network Systems, 2020, vol. 8, no 1, p. 487-499.